10.21611/qirt.2020.157
15th Quantitative InfraRed Thermography Conference

Temperature Calculation of a Steel Plate under Kerosene Flame Attack using Two-Colour Pyrometry

by Serge-Olivier Gnessougou*, Marc-Antoine Langevin**, Clemente Ibarra Castenado*, Alain deChamplain*** and Xavier Maldague*

*Multipolar infrared Vision Infrarouge Multipolaire (MIVIM), Université Laval, Electrical and Software Engineering department, Pavillon Adrien-Pouliot 1065, avenue de la Médecine Québec (Québec) G1V 0A6Y, serge-olivieradam.gnessougou.1@ulaval.ca , clemente.ibarra-castanedo@gel.ulaval.ca , xavier.maldague@gel.ulaval.ca

**Telops Inc, 100-2600, Avenue St-Jean-Baptiste Québec (Québec), Canada G2E 6J5, marc-antoine.langevin@telops.com

*** Combustion Laboratory, Université Laval, Mechanical Engineering department, Pavillon Adrien-Pouliot, avenue de la Médecine, local 1504 Québec (Québec) G1V 0A6Y, alain.dechamplain@gmc.ulaval.ca

Abstract

The temporal change in temperature for the surface of a steel plate under kerosene flame exposure is measured without contact using the two-colour pyrometry technique. The pyrometric temperatures from room temperature to 600°C were obtained with a multispectral infrared camera equipped with a fast rotating wheel (50x8 to 365/8 frames/seconds) with two "*through flame filters*" at 3800 nm and 3950 nm. The calculated pyrometric temperatures were validated with the temperature data of three thermocouples incorporated at three different locations in the back of the steel plate (T1 in the center of the kerosene flame, T2 & T3 are at 5 & 13 cm from center).

1. Introduction

During the combustion of a material, the emissivity at the surface changes [1,2,3] and then it is difficult to obtain accurate temperature with one infrared camera. Usually, the standard temperature measurement is inaccurate since heat transfer calculations can not be accounted for properly with thermocouples (TCs). The two-color pyrometry is well known to be non-destructive, noncontact, fast and reliable systems even in harsh environmental conditions. We often use two different but closed wavelengths with two different detectors (cameras) to have the radiation from the observed body and with the radiation of these wavelengths we calculate the pyrometric temperature [2]. However, the use of two cameras simultaneously can make this method expensive. Here, a multispectral infrared camera equipped with a fast-rotating wheel with different spectral filters was used to study the combustion of a steel plate heated with a kerosene burner, that reached a temperature of 1200°C. Two filters (filter#1 = 3800 nm and filter#2 = 3950 nm) which are transparent to the wavelengths of the kerosene flame were used for studying the changing material properties under flame attack. The pyrometric temperatures obtained were validated with the temperature data of three embedded thermocouples.

Principles

The thermal radiation of a body at one wavelength is given by the infrared camera in the form of a signal (intensity) according to the following relation [2]:

$$\boldsymbol{I_i = K_i \lambda_i^{-5}\, \epsilon(\lambda_i, T) \exp\left(-\left(\frac{C_2}{\lambda_i T}\right)\right)} \tag{1}$$

Where K_i is a constant related to the detector in the IR camera, ϵ the emissivity, λ_i the wavelength in µm, T the temperature in K and C_2 a constant related to Planck's law with a value of $1.4388\text{x}10^{+4}$ µm•K.

The ratio *R* of two signals measured at a given temperature for the two different wavelengths is then calculated with the equation:

$$\boldsymbol{R}_{\,heated\;steel\;plate} = \frac{I_{1-heated\,steel\,plate}}{I_{2-heated\,steel\,plate}} = \frac{K_1}{K_2}\frac{\lambda_1^{-5}}{\lambda_2^{-5}}\frac{\epsilon(\lambda_1,T)}{\epsilon(\lambda_2,T)}\,\boldsymbol{exp}\left(-\left(\frac{C_2}{T}\right)\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)\right) \qquad (2)$$

For two closed wavelengths like in our case here, $\frac{\epsilon(\lambda_1,T)}{\epsilon(\lambda_2,T)} \approx \mathbf{1}$ and Eq. (2) can be rewrite:

$$\mathrm{R(T)}_{\,\mathrm{heated\;steel\;plate}} = \mathrm{K}_3\ \ \exp\left(-\left(\frac{\mathrm{C}_2}{\mathrm{T}}\right)\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)\right) \qquad (3)$$

With a calibration with a prior calibration with a black body (emissivity = 1), we can then find the pyrometric temperature of the heated steel plate following:

$$\boldsymbol{R}(\boldsymbol{T})_{\,Black\;Body} = \frac{I_{1-Black\,Body}}{I_{2-Black\,Body}} \approx \ \boldsymbol{R}(\boldsymbol{T})_{\,heated\;steel\;plate} = \frac{I_{1-heated\,steel\,plate}}{I_{2-heated\,steel\,plate}} \qquad (4)$$

2. Apparatus

Fig.1b in the appendix shows the setup used to calculate the pyrometric temperature. A kerosene burner that reached a temperature of 1200°C heated a steel plate. A multispectral infrared camera (Telops MS M100k) is used to observe the steel plate exposed to the opened flame and measure the ratios $\mathbf{R(T)}_{\,\mathbf{heated\;steel\;plate}}$ and $\mathbf{R(T)}_{\,\mathbf{Black\;Body}}$. The IR camera is equipped with a fast-rotating wheel with two filters which are transparent to the wavelengths of the strongly emitting kerosene flame (filter#1 = 3800 nm and filter#2 = 3950 nm – 640x512 pixels and 50/8 frames/seconds). Calculations of the pyrometry temperatures are then completed using an algorithm in MATLAB based on Eq (4).

.

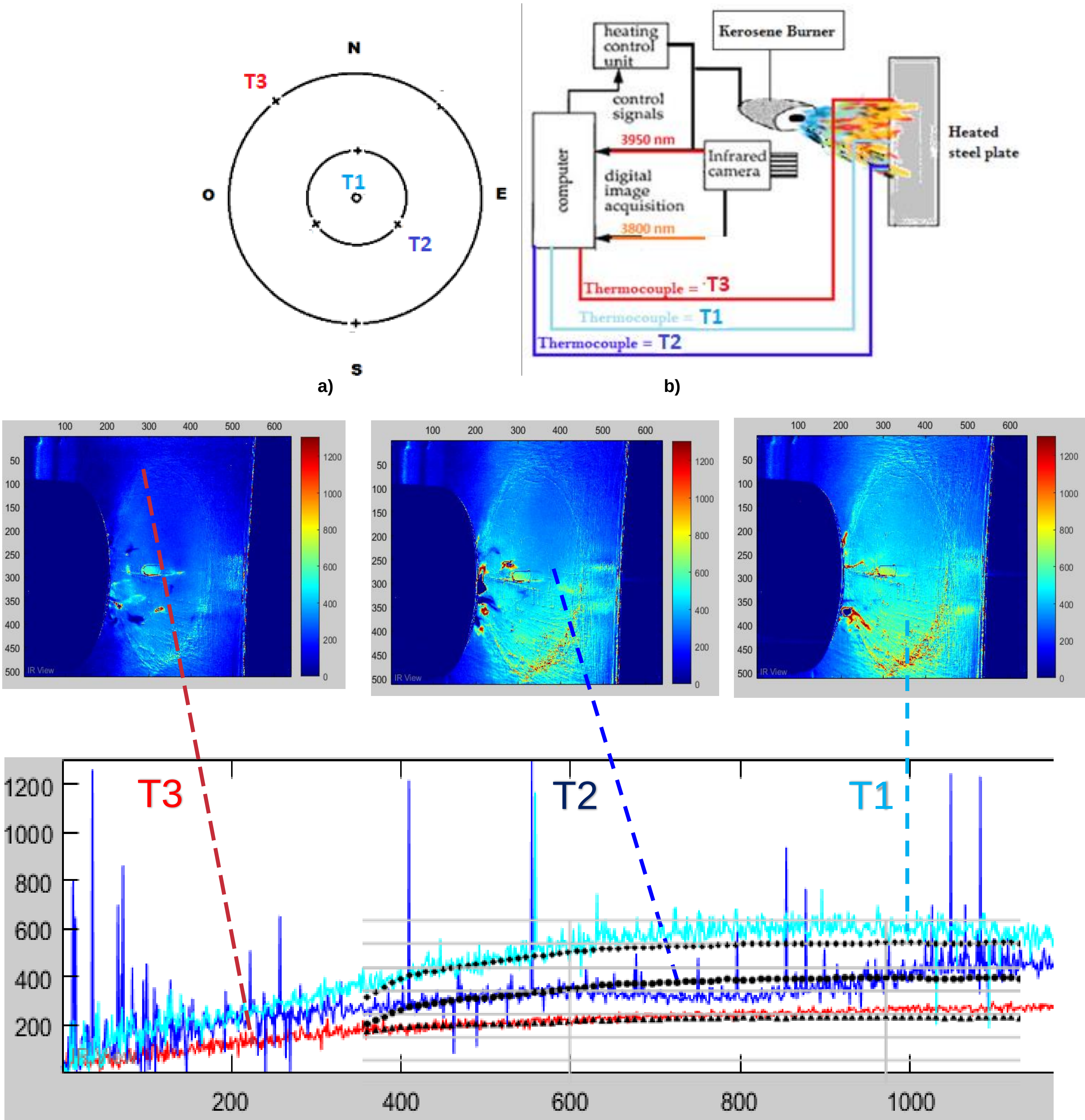
3. Results

The Fig.1c in the appendix shows some relevant results. Pyrometric temperatures (Fig. 1c) average value of 600ºC at the center (T1) as shown on Fig. 1a, but rapid transient flickering flame picked up by IR camera to show variations at ±100°C. At the spot T2, 5 cm from the center the temperatures average value at 400ºC but showing large transient spike picked up by the IR camera to show maximum flame temperature of 1200°C resulting from soot spots at T2 (Fig. 1c). Soot more present at that location where fuel droplets escape with higher speed of combustion gases sandwiched between inner low speed swirled recirculating flow and outer colder entrained ambient air also at much lower speed [4]. At the spot T3, 13 cm from the center, the temperatures average value at 300ºC at 13 cm (T3) with much lower fluctuations and in good agreement with TC data (Fig.1c).

REFERENCES

[1] DeWitt, D.P., Theory and Practice of Radiation Thermometry. 1988: Wiley.
[2] Maldague, X., Theory and Practice of Infrared Technology for Nondestructive Testing. 2001: Wiley.
[3] Bergman, T.L., Lavine, A.S., Incropera, F.P., and Dewitt, D.P., Fundamentals of Heat and Mass Transfer. 2011.
[4] Paquet, B., Boudreau A. and De Champlain, A., Proof of Concept of FAA Compliance with Engine Fire Protection Requirements using an IR Camera. 2014, Université Laval: Québec.

4. APPENDIX



c)

Fig. 1. a) Location of thermocouples on the non-burning steel plate. T1 is in the center of the flame, T2 & T3 are at 5 & 13 cm from center. b) Scheme of the experimental setup for the thermal diffusivity at room temperature. c) Calculated pyrometric temperature (°C) of the non-burning material vs time (s) validated with superposed thermocouple data (Black Symbols).